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Laser Ranging Network Performance and Routine Orbit Determination at D-PAF

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Summary

ERS-1 is now about 8 months in orbit and has been tracked by the global laser network from the very beginning of the mission. The German processing and archiving facility for ERS-1 (D-PAF) is coordinating and supporting the network and performing the different routine orbit determination tasks.

This paper presents details about the global network status, the communication to D-PAF and the tracking data and orbit processing system at D-PAF. The quality of the preliminary and precise orbits are shown and some problem areas are identified.

1. Background

On July 17, 1991, the first European (ESA) Remote Sensing Satellite (ERS-1) was successfully launched from Kourou, French Guayana. The satellite is equipped with a number of active microwave instruments for the monitoring of the Earth's environment (see figure 1). In order to make full use of the measurements the ERS-1 orbit has to be known very precisely. For this purpose ERS-1 is carrying a laser retro-reflector and, as an experiment, the Prare system (Precise Range and Range Rate Equipment). After the failure of the Prare system due to a radiation damage the satellite laser ranging (SLR) measurements are the basis for the precise orbit determination.

ERS-1 is flying in a sun-synchronous circular orbit (quasi-polar) at a mean altitude of 785 km and an inclination of 98.5 degrees with different ground repeat cycles (see table 1). The Kepler period is about 100.5 min.

To keep the satellite ground tracks within +-1 km deadband (first 6 months +- 2 km) so called maintenance manoeuvres have to be executed, which take place usually every two to four weeks depending mainly on the solar activity.

Figure 1: ERS-1 Satellite

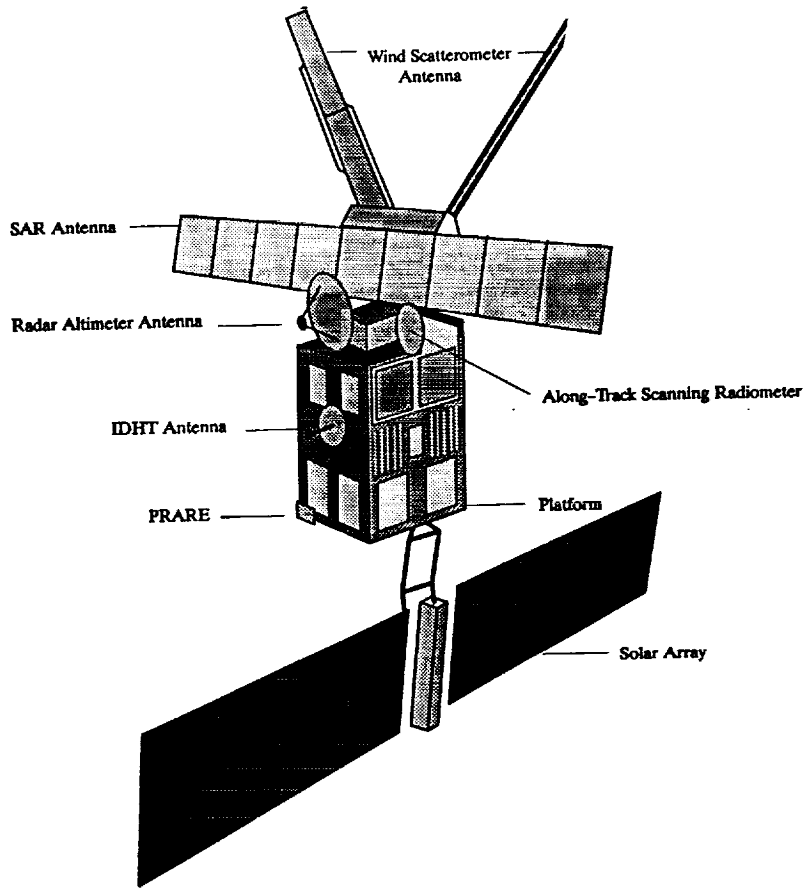


Table 1: ERS-1 Orbit Characteristics

	Repeat Cycle 3 days	35 days	176 days
Revolutions per cycle Revs per day	43 revs 14 + 1/3	501 revs 14 + 11/35	2521 revs 14 + 57/176
Mean Semi-Major Axis [km] Mean Inclination [Degrees] Mean Eccentricity Mean Argument of Perigee Mean local solar time of descending node Longitudinal phase (ascending node) [degrees] (1) Venice (2) ICE Orbit	7153.138 98.516 1.165×10^{-3} 90.0 deg 10h 30min 24.36 East(1) 128.2 West(2)	7159.4965 98.5429 1.165×10^{-3} 90.0 deg 10h 30min 20.9605 East	7156.30 98.5114 1.165×10^{-3} 90.0 deg 10h 30min not decided
Duration	26/07/91-12/12/91 (1) 23/12/91-30/03/92 (2) 16/12/93-01/04/94 (2)	2/4/92-15/12/93	8/4/94-...

2. ERS-1 Laser Tracking Network

The ERS-1 satellite is tracked by a network of globally distributed stations which were funded by many different institutes. In table 2 the stations are listed along with their ERS-1 tracking periods.

In figures 2 to 4 the geographical distribution of the stations is plotted for the first three orbit phases (see table 1). As can be seen, most of the tracking stations are located in Europe and North America. The southern hemisphere is covered only by up to four SLR stations and none of them is located in the south African region. The plots show also the actual tracked ERS-1 orbital passes.

Figure 2: SLR Tracking Coverage within the Commissioning Phase (Venice Orbit)

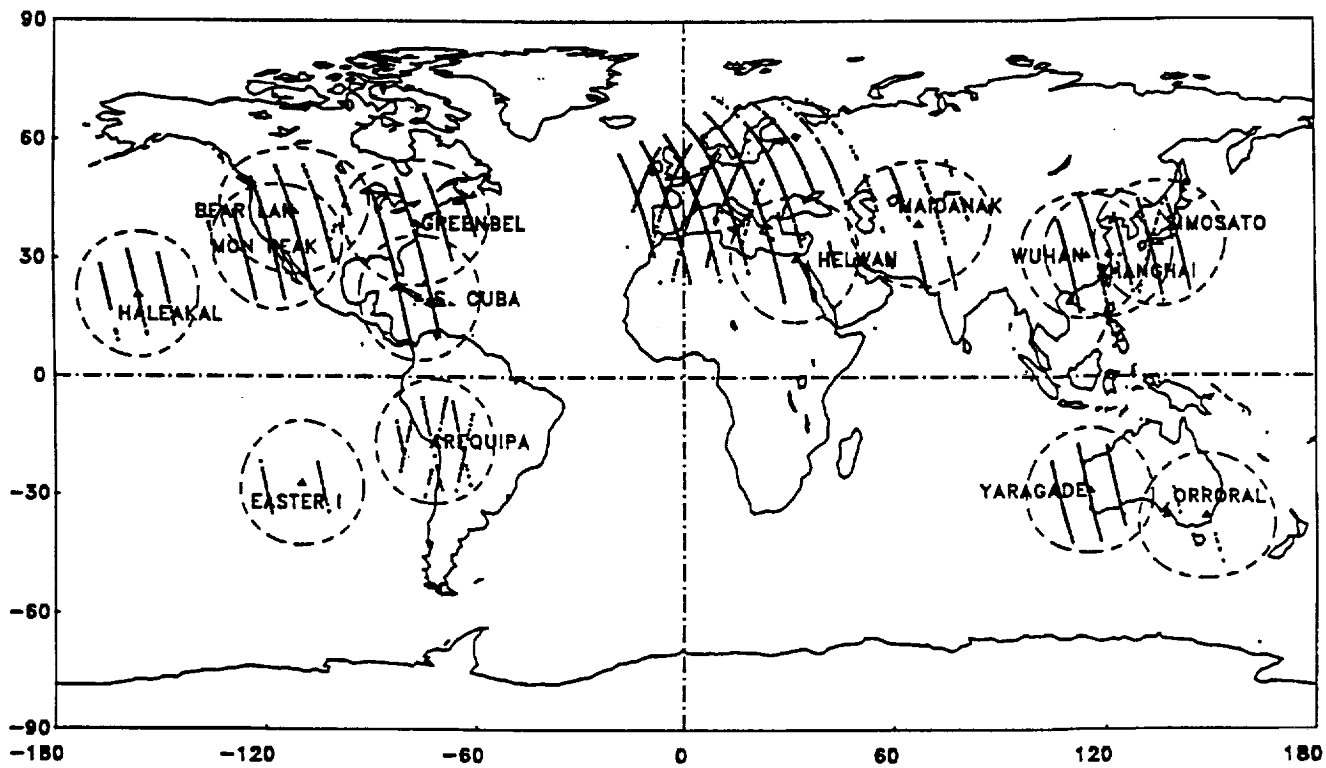


Table 2: ERS-1 Tracking Network Stations

ID	Name	Location	System	Tracking Periods
1181	Potsdam	Germany, Europe	fix	910720 ..
1863	Maidanak	Russia,	fix	910724 ..
1864	Maidanak	Russia,	fix	920421 ..
1873	Simeiz	Russia, Europe	fix	910723 .. 910829
				920501 ..
1884	Riga	Latvia, Europe	fix	910731 .. 911028
				920225 .. 920226
				920401 ..
1893	Katzively	Russia, Europe	fix	920422 .. 920515
1953	Santiago de Cuba	Cuba, Carribean	fix	910808 .. 910922
				911127 ..
7046	Bear Lake	USA, North America	TLRS-4	910906 .. 911015
7080	Fort Davis	USA, North America	fix	910822 .. 910822
				911121 .. 920124
				920318 ..
7090	Yarragadee	Australia	MOBLAS-5	910731 ..
7097	Easter Island	Chile, Pacific	TLRS-2	911018 .. 920311
7105	Greenbelt	USA, North America	MOBLAS-7	910802 ..
7109	Quincy	USA, North America	MOBLAS-8	911211 ..
7110	Monument Peak	USA, North America	MOBLAS-4	910725 .. 920306
				920504 ..
7210	Haleakala	Hawaii, USA	fix	910731 ..
7236	Wuhan	China, Asia	fix	910929 .. 920222
				920404 ..
7403	Arequipa	Chile, South America	TLRS-3	910731 .. 911010
7512	Kattavia	Greece, Europe	MTLRS-1	920328 .. 920426
7542	Monte Venda	Italy, Europe	MTLRS-2	910729 .. 910917
7810	Zimmerwald	Switzerland, Europe	fix	910719 ..
7811	Borowiec	Poland, Europe	fix	910807 .. 910818
				911002 .. 911006
				920107 .. 920121
7824	San Fernando	Spain, Europe	fix	911029 .. 920327
				920505 ..
7831	Helwan	Egypt, North Africa	fix	910803 .. 911131
				920226 ..
7835	Grasse	France, Europe	fix	910717 ..
7837	Shanghai	China, Asia	fix	910816 ..
7838	Simosato	Japan, Asia	fix	910720 ..
7839	Graz	Austria, Europe	fix	910722 ..
7840	Herstmonceux	Great Britain, Europe	fix	910719 ..
7843	Orroral	Australia	fix	910725 .. 910729
				911117 .. 911117
				920119 .. 920127
				920414 ..
7882	Cabo San Lucas	Mexico	TLRS-4	920319 ..
7883	Ensenada	Mexico	TLRS-4	911113 .. 911126
				920109 .. 920208
7907	Arequipa	Chile, South America	fix	911129 .. 911129
7918	Greenbelt	USA, North America	TLRS-3	920107 .. 920115
				920404 ..
7939	Matera	Italy, Europe	fix	910724 ..
8834	Wettzell	Germany, Europe	fix	910918 .. 910918
				920305 ..

MOBLAS	mobile laser system
MTLRS	modular transportable laser system
TLRS	transportable laser system

Figure 3: SLR Tracking Coverage within the First Ice Phase (Ice Orbit)

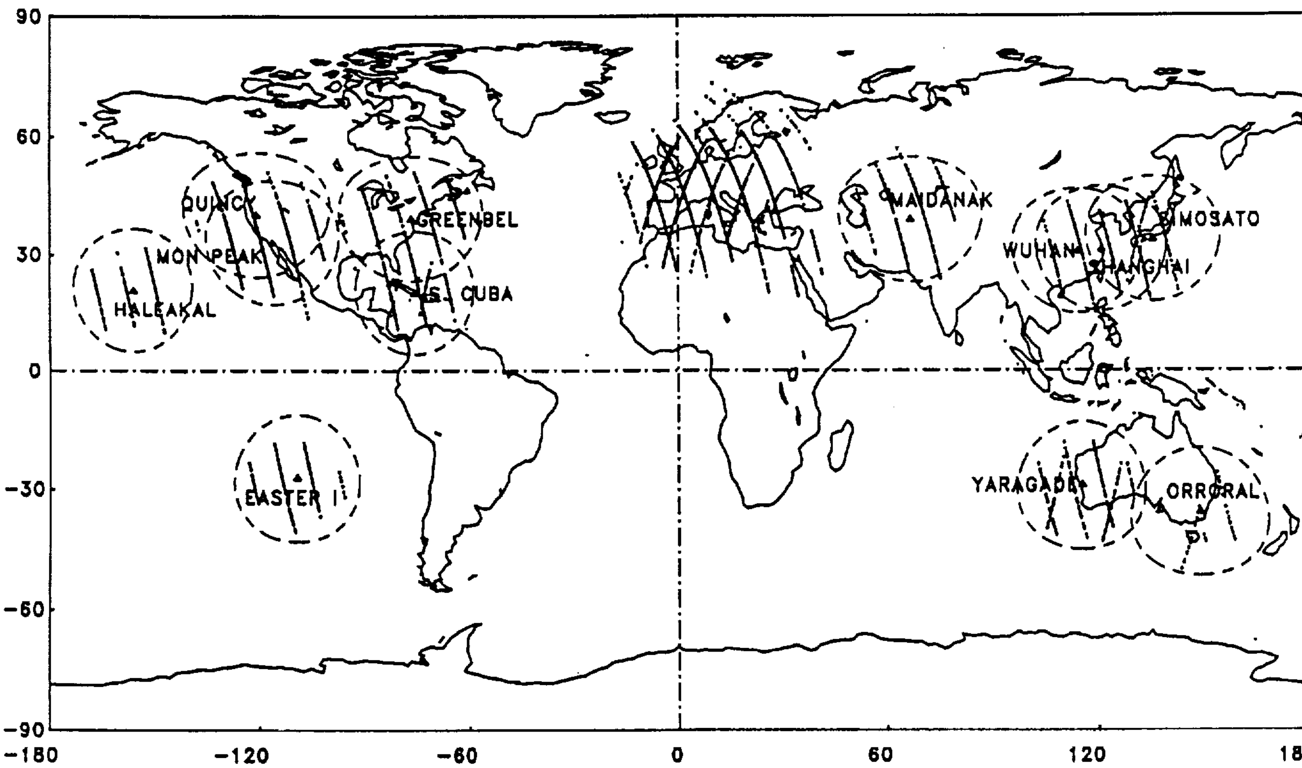
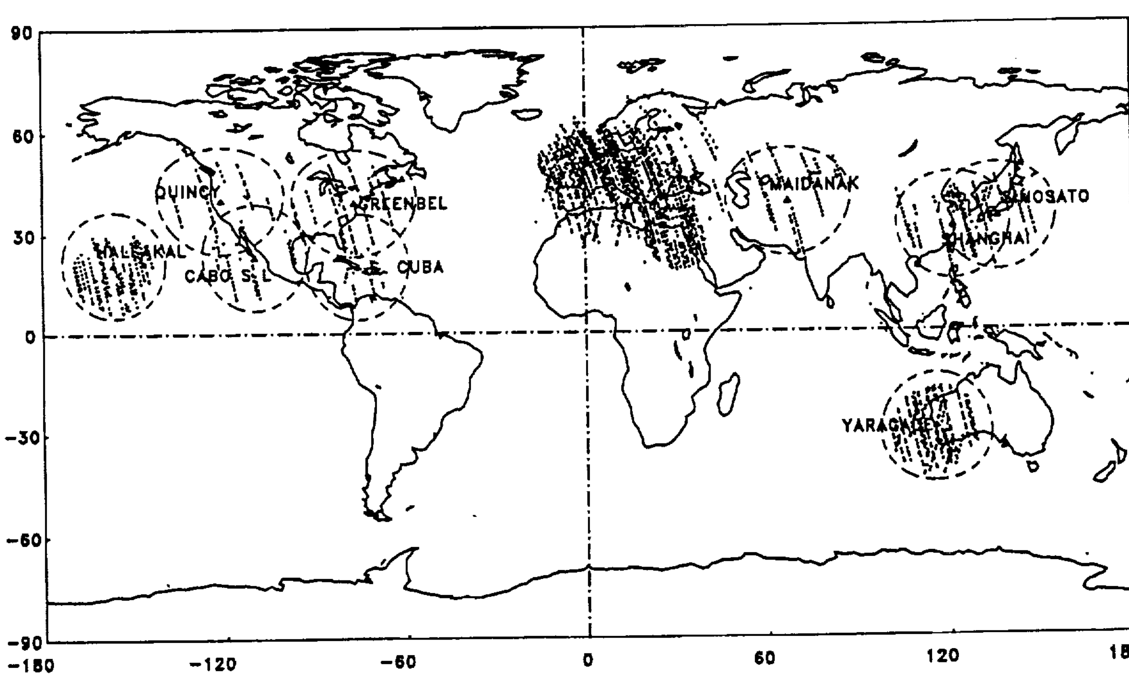


Figure 4: SLR Tracking Coverage within the first Month of the Multidisciplinary Phase



3. Data Flow to D-PAF Systems

Soon after the tracking of a satellite pass the SLR data is preprocessed at the station:

- a first data screening is performed by most of the stations;
- then from each pass about 50 data points were selected (quick-look (Q/L) data) or
- the measurements were compressed into onsite normal points (ONP).

This Q/L or ONP data is then transmitted to the Data Analysis Center at D-PAF. There are two centers collecting and forwarding the data: the data from the CDSLR stations is transmitted via existing internal links to the CDSLR headquarters and then forwarded to CDDIS; the second center is at the European Data Center (EDC) at DGFI. EDC is collecting all data from the European systems (EUROLAS) and also from stations in Russia, Cuba and China. From these two data centers D-PAF is retrieving the collected data files on a daily basis and merges them with data from those stations which have sent their data directly to D-PAF.

The data transmission is performed by using all currently available communication links: telex, Span, Bitnet, Internet, GE/MARK III and ftp.

After having applied all necessary corrections the full tracking data set (full-rate (FR)) is transmitted to the two centers, usually by CCT or Span. Again D-PAF retrieves the FR data sets from CDDIS and EDC and merges them with the directly received files.

It has to be noted, that all three parties exchange their data to have the full information available for all partners. In the beginning of the mission when EDC was not established D-PAF performed the EDC activities too.

According to the work distribution between the four European processing and archiving facilities (PAF) D-PAF is responsible for the generation of operational precision orbital products and for a processing of SAR data. In order to fulfill these tasks D-PAF has set up a number of processing systems. Used for the orbit generation are:

- the telecommunication system (TCS)
- the data management system (DMS)
- the **tracking and orbit determination system (TOS),** which consists of the following subsystems:

  preprocessing subsystem: preprocessing of incoming data, generation of normal points from laser and altimeter data

  orbit determination subsystem: differential orbit correction by numerical integration methods, quality control, generation of numerical and graphical products

  orbit prediction subsystem: orbit extrapolation, generation of orbit prediction sets in different formats, generation of time bias functions, quality control

  earth gravity modelling subsystem: processing of surface gravity data, reduction and solution of normal equation systems, quality control

4. Station Performance

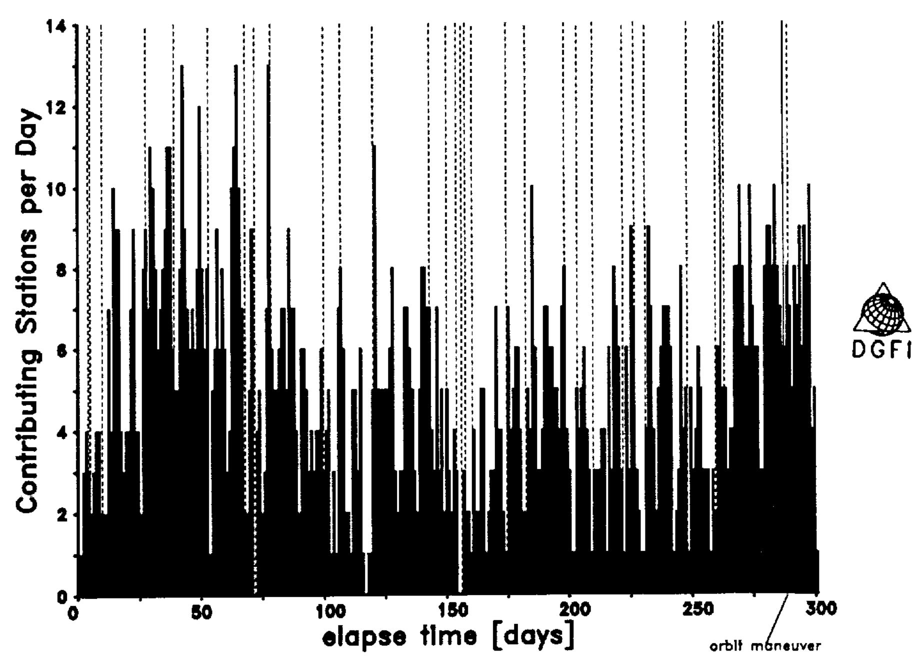
At D-PAF all incoming data is checked for quality and statistics are generated. On a weekly basis Q/L reports are generated presenting incoming data statistics and data quality check information. This paragraphs will present some of the statistical information.

As already seen in figures 2 to 4 only a small part of the ERS-1 orbital path is observed by the ground stations and this is mainly located north of the equator. Especially over South America the situation became worse from the first to the second phase and in the first month of the multidisciplinary phase there is no tracking in that part of the world.

From the figures it is also visible that mainly the ascending arcs were observed by the stations, while only a few descending arcs were tracked. The reason probably is that the descending passes can be tracked only during daylight.

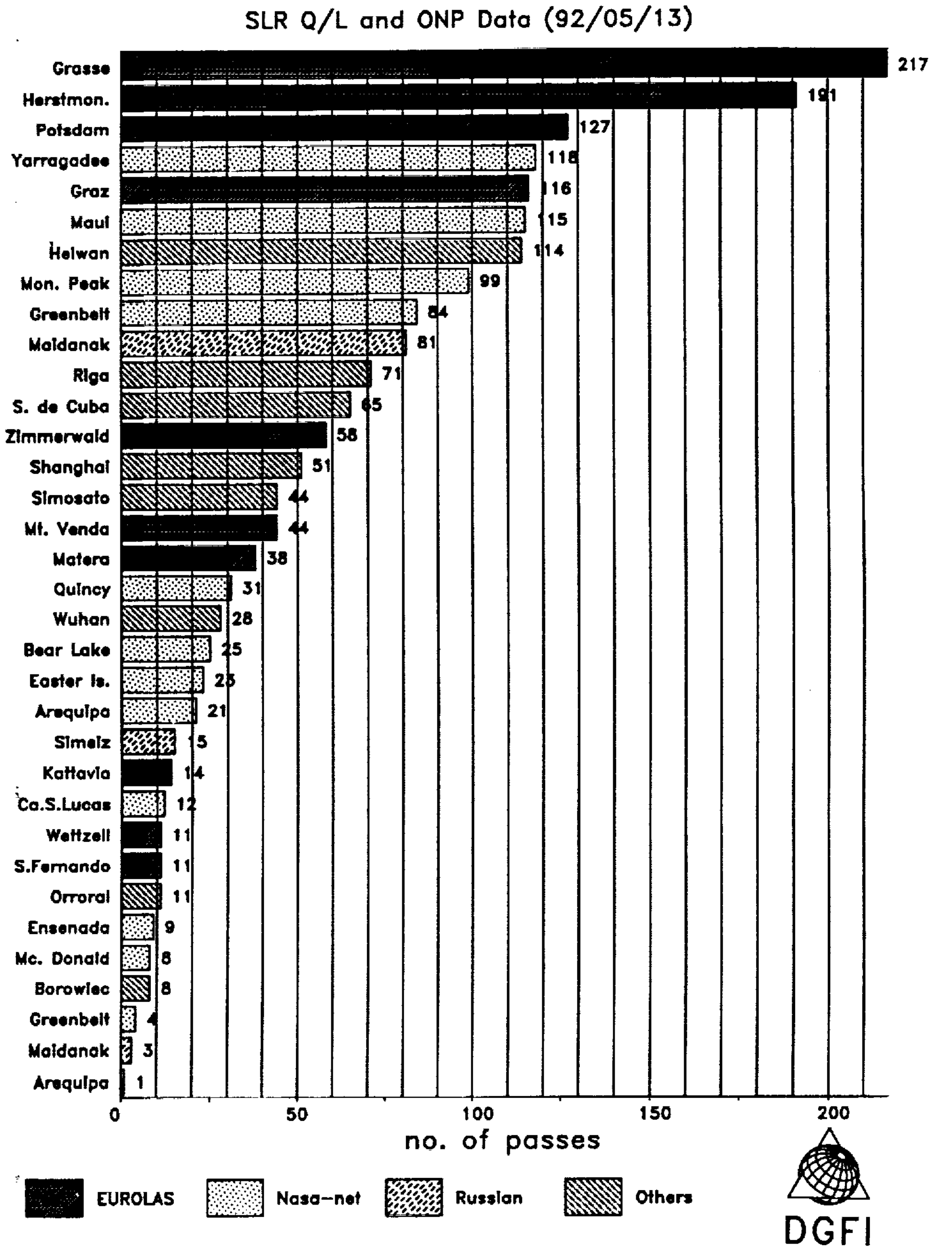
Figure 7 presents the variation in the number of stations observing ERS-1 per day. It ranges from 0 to 13 and shows clearly a decrease for the months October 91 to March 92, when ERS-1 was not in sunlight for many of the stations. A corresponding trend is visible in figure 9 which depicts the number of passes per week. For an arc of 7 days about 30 to 60 passes are available.

Figure 7: ERS-1 SLR Stations per Day



There is also a wide range in the number of passes being tracked by different stations. As can be seen from figure 8 this varies from 1 to 217. But one has to keep in mind that not all stations were continously tracking, some were occupied only for a short while (e.g. Monte Venda, see table 2). The tracking contribution of some stations to the total ERS-1 tracking ranges from a few percent to almost 15 percent (Grasse).

Figure 8: Acquired ERS-1 SLR Passes per Station



Not only the data quantity is varying from station to station, but also the data quality is different. There are some stations with single shot precision of about 20 cm and others with 1 cm and less. Figure 10 depicts the station performance in terms of single shot and 15 sec. normal point accuracy for some stations.

Figure 9: Acquired ERS-1 SLR Passes per Week

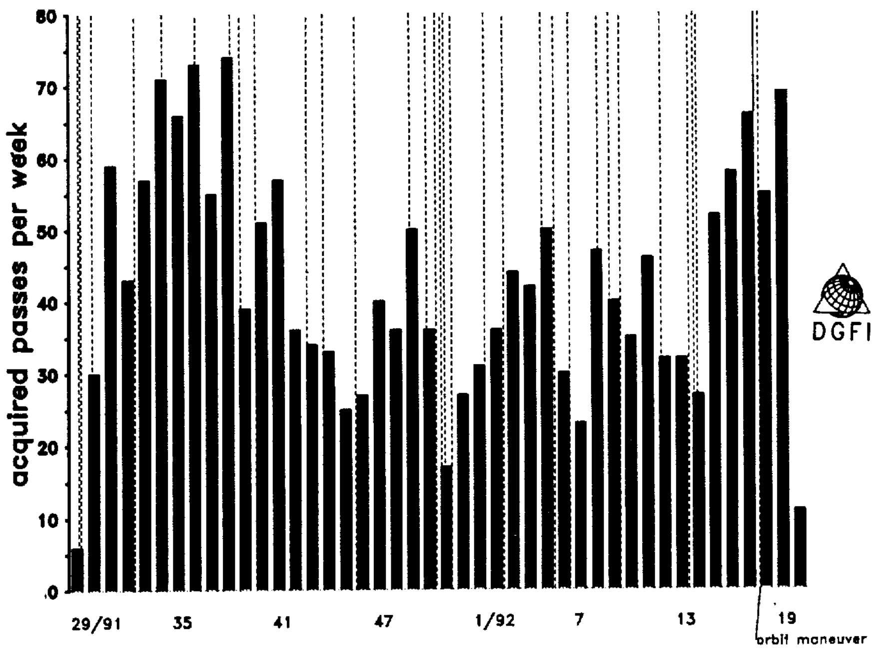
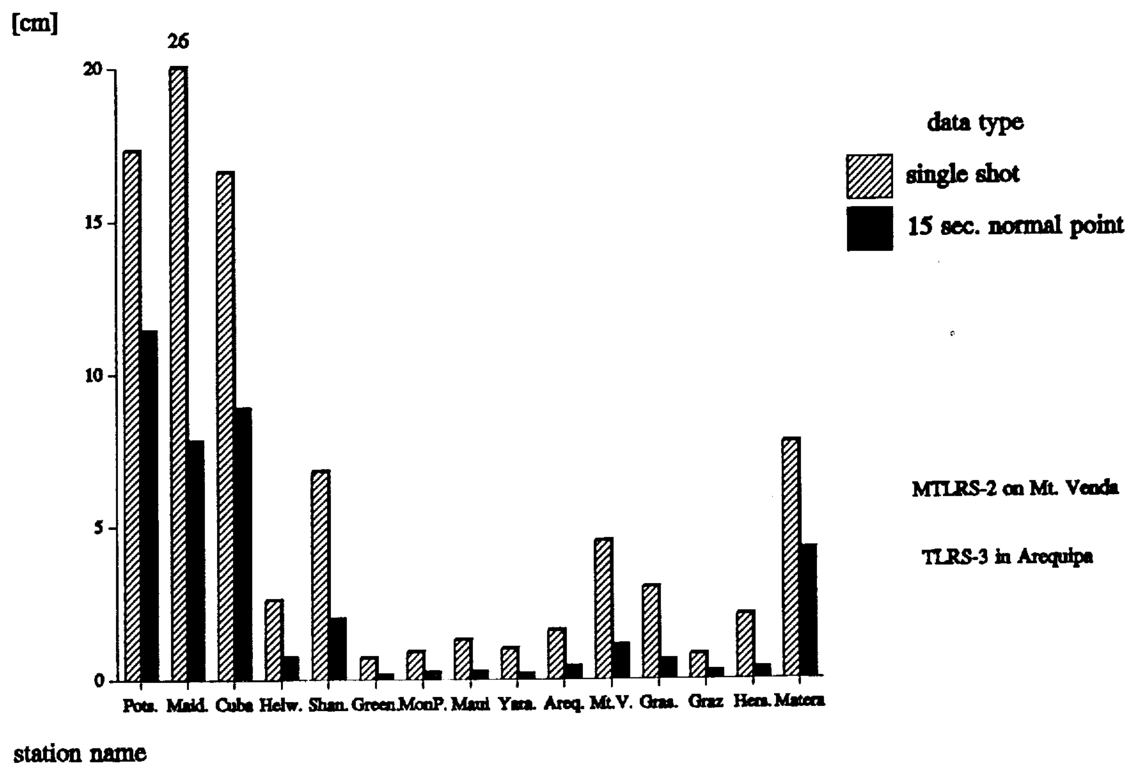


Figure 10: ERS-1 Tracking Precision per Station (cm)



5. Orbit Determination at D-PAF

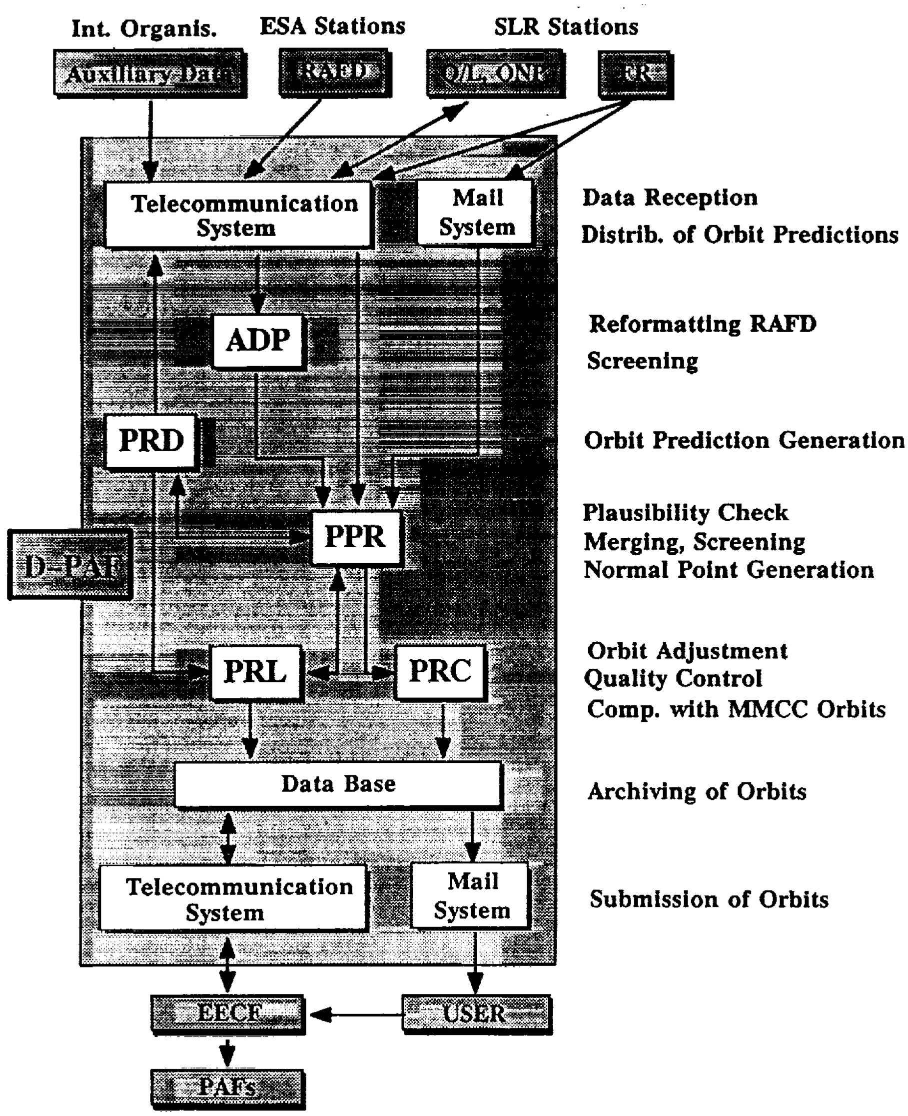
In order to provide ERS-1 precision orbits the following ERS-1 orbital products are routinely generated and distributed:

- orbit predictions and time bias functions
- preliminary orbits
- precise orbits

The latter two products are official ESA products, while the first one is an internal one. More details about the ERS-1 orbit predictions can be found in König et.al. (1992). A detailled description of all radar altimeter and tracking data products is presented in Bosch et.al. (1990).

The overall data flow for the orbit determination processes is explained in figure 11.

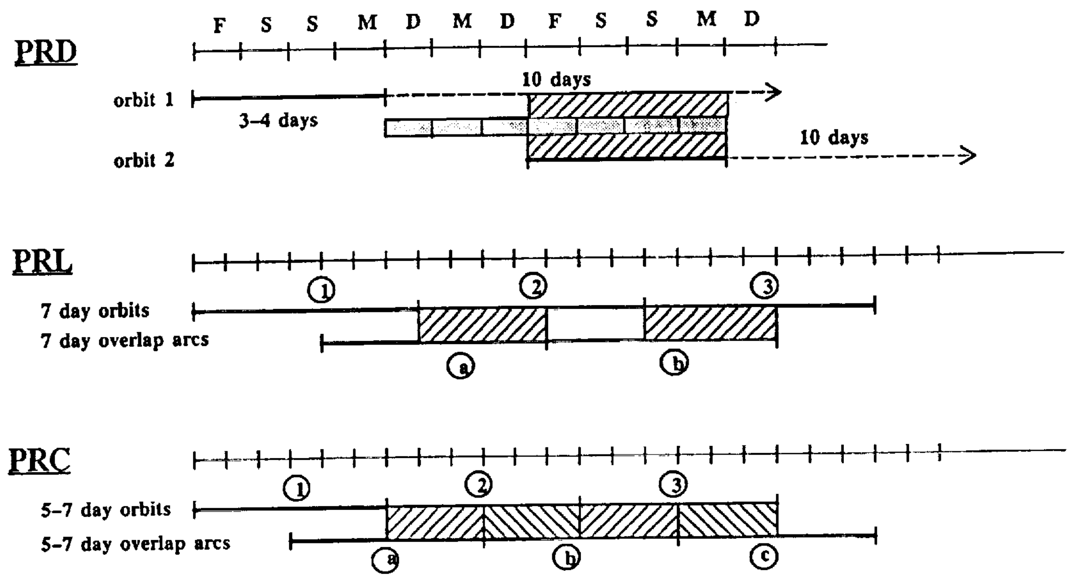
Figure 11: Orbit Determination Data Flow



The processing schemes are outlined in figure 12 for manoeuvre free periods.

Figure 12: Processing Scheme

(for manoeuvre free periods)



5.1 Preliminary Orbit Determination

Preliminary orbits are computed on a weekly basis by using Q/L laser and radar altimeter fast delivery (RA-FD) data and are usually available within two weeks. Both data sets are compressed into normal points (15 sec. bins for SLR, 10 sec. bins for RA-FD) after first quality checks. As can be seen from figure 14, the use of RA-FD data improves the global coverage especially for arc with only a few SLR passes.

In manoeuvre free periods weekly arcs are computed plus another 7-day arc which is overlapping by 3-4 days and is used for quality assessment (see figure 12). The models for the orbit determination are described in Zhu and Reigber (1991) and Massmann et.al. (1992). Solve-for parameters are the six orbital elements at epoch, one solar radiation coefficient, daily/half-daily drag coefficients, altimeter range bias (if RA-FD data is used) and station coordinates (for new stations only).

The resulting orbital fits are usually around 50-80 cm, in case of bad data coverage up to 130 cm. Figure 13 presents the quality control results from overlapping arcs for 1991 and 1992. The large values in November 91 are resulting from a period with no useful RA-FD data and only a very few laser passes. The same hold for the end of December 91.

Figure 13: PRL Precision Assessment by Overlapping Arc Comparison

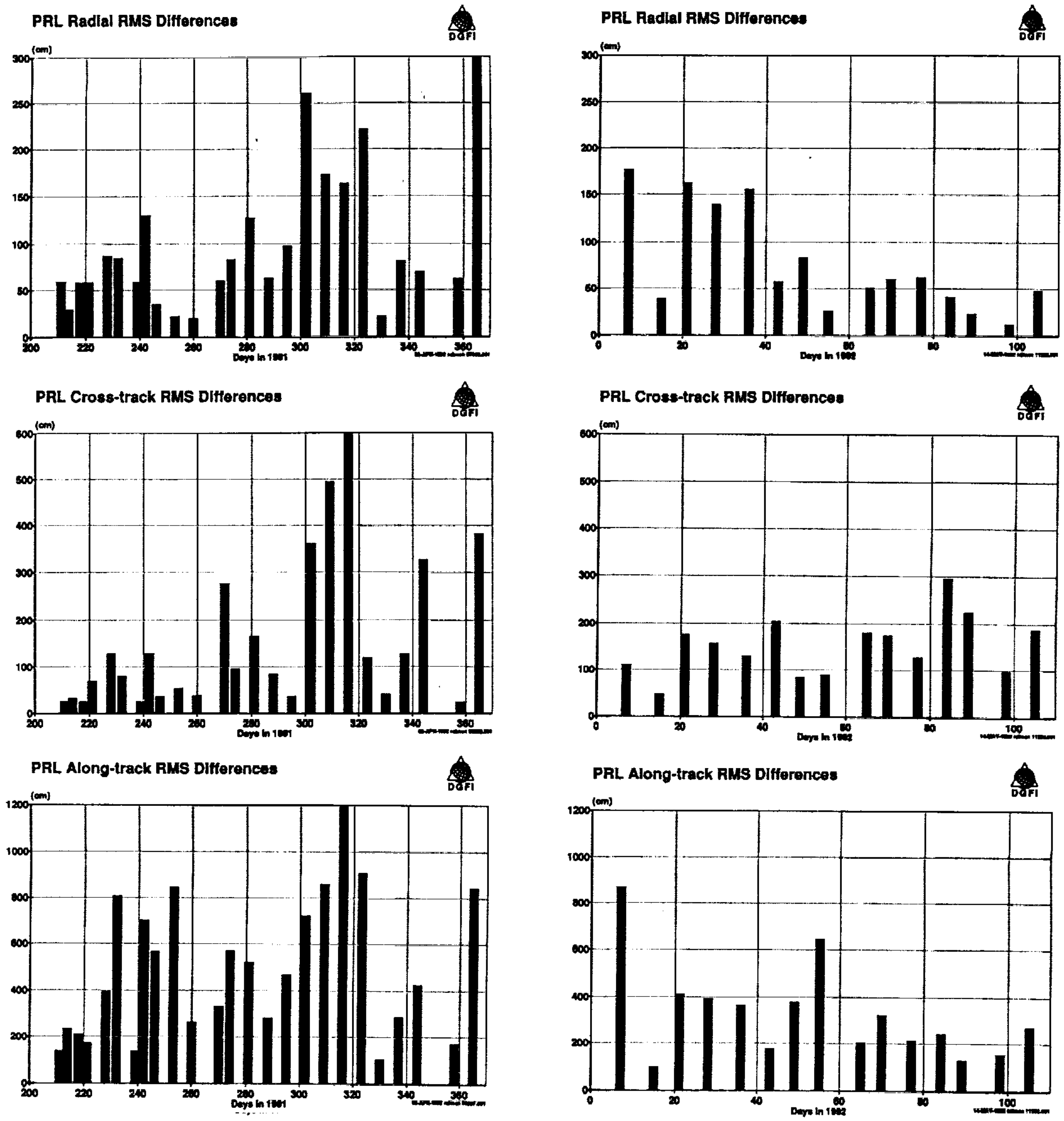
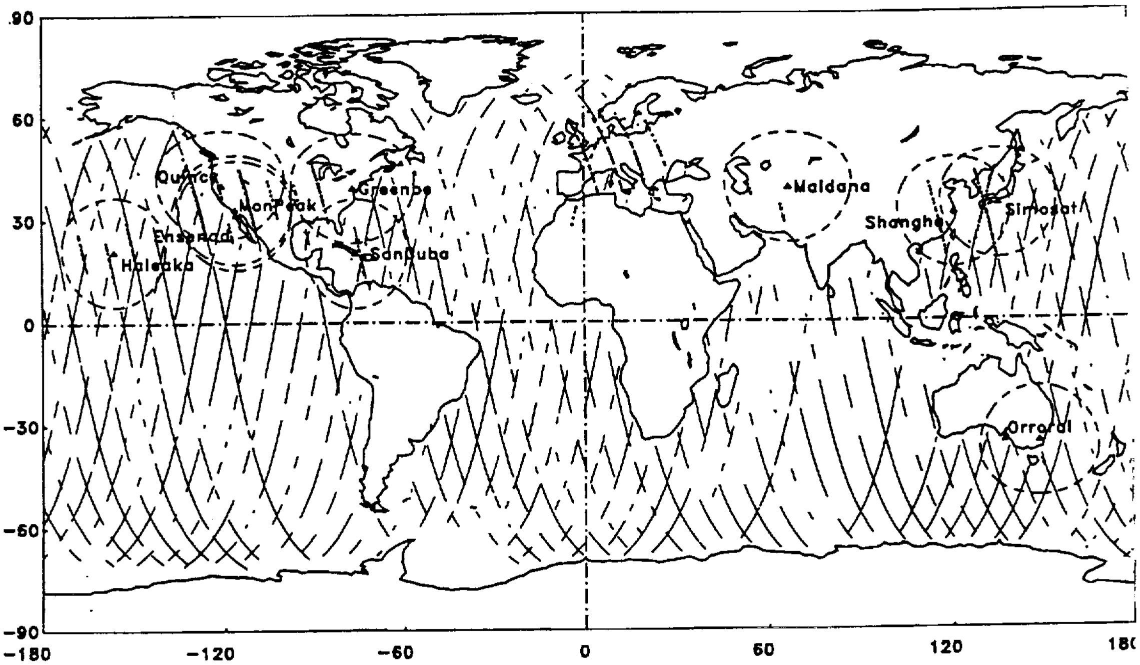


Figure 14: Input Example for the Preliminary Orbit Determination

(January 20-27, 1992)



5.2 Precise Orbit Determination

The precise orbits are based up to now only on laser data which have been compressed into 15 sec. normal points. The orbits are computed with a delay of 3-6 months depending on the availability of all FR laser data at D-PAF. The arc length is choosen to fit as good as possible in between two manoeuvres and is usually in the range of 5-7 days. The quality control is also performed by overlapping arc comparison. Models and solve-for parameters are the same as for the preliminary orbits, except the earth rotation parameters, the geomagnetic indices and the solar flux data, which are now the official final values instead of predicted or preliminary ones.

Figure 15 presents the resulting rms orbital fit values for the precise orbit arcs generated up to now while figure 16 shows the quality estimates from the overlapping arc comparison. When comparing figure 13 and 16 one has to be careful, because the arcs are not the same. But generally one can say that the PRC results are more homogeneous and do not show large spikes due to better input data and a more intensive data handling. The most interesting radial component of the orbit seems to be accurate to 50 to 60 cm.

Figure 15: PRC Orbital Fits

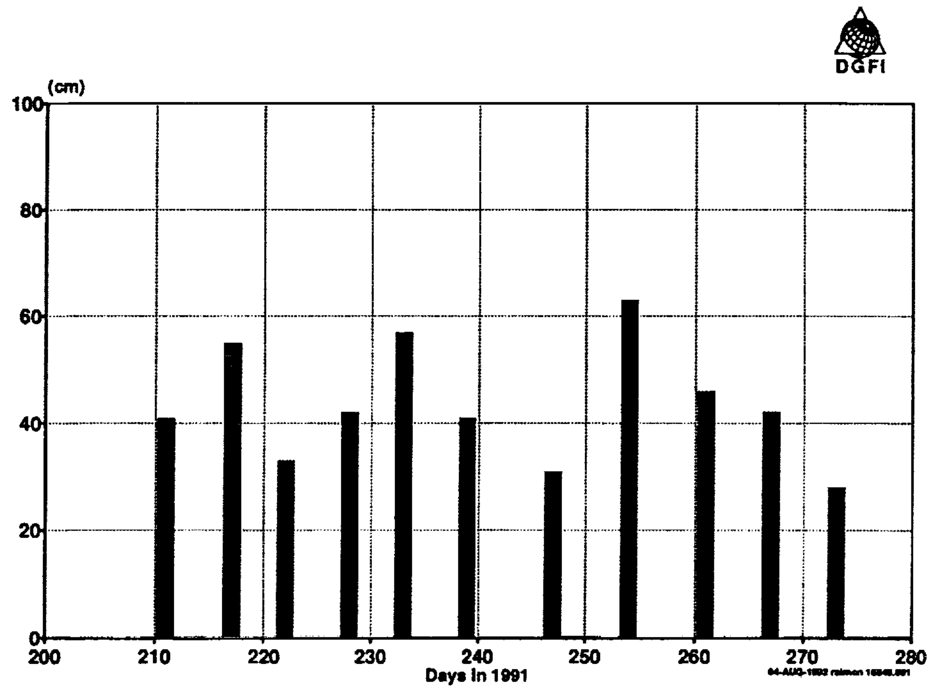
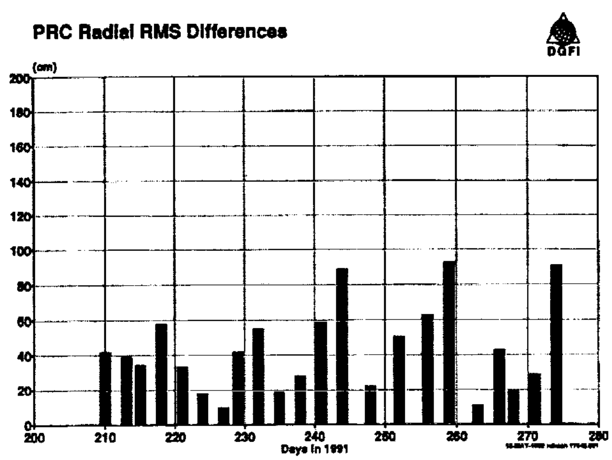
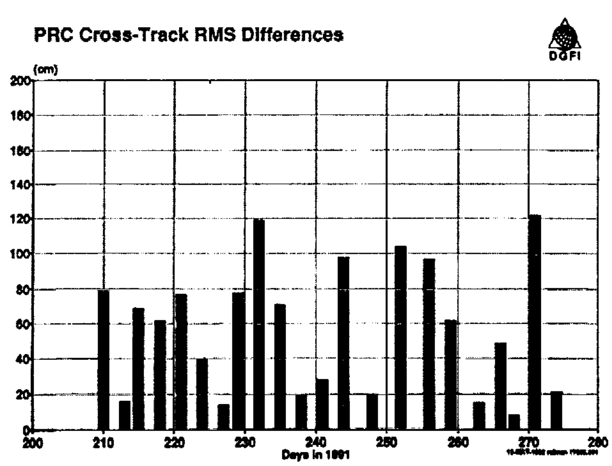
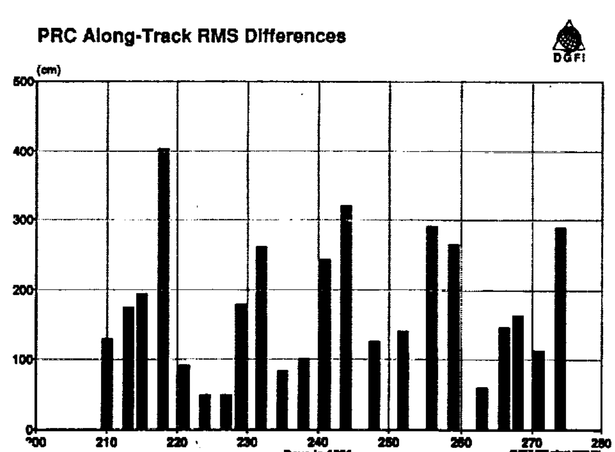


Figure 16: PRC Precision Assessment by Overlapping Arc Comparison







6. Conclusion

Soon after the ERS-1 launch DGFI/D-PAF has started the orbit computations and demonstrated its capability to generate good quality orbits on an operational basis. On the other hand the SLR stations have demonstrated their capability to track ERS-1 and provide high quality tracking data.

Nevertheless there are a few things that could be improved: The accuracy of the generated preliminary and precise orbits is very much limited by the spatial and temporal coverage of the SLR data.

Up to now there are only a few stations in the southern hemisphere of which only one has a good tracking record. On the African continent only one tracking station can be found and that is located in North Africa (Helwan). On the northern hemisphere some gaps can be identified over Russia.

The temporal coverage suffers from the fact that mostly the ascending ERS-1 arcs (night passes) were tracked by the stations. A reason for that is partly the missing daylight tracking capability of the station, partly tracking restrictions and partly man power problems.

Due to the data coverage it is difficult to model large ERS-1 drag perturbation, especially during periods with high solar activity. Tests are initiated to improve this by using either drag information derived from Spot2 Doris data or by using crossover altimeter data.

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